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RANGE AND STOPPING POWER CALCULATIONS IN NUCLEONICA

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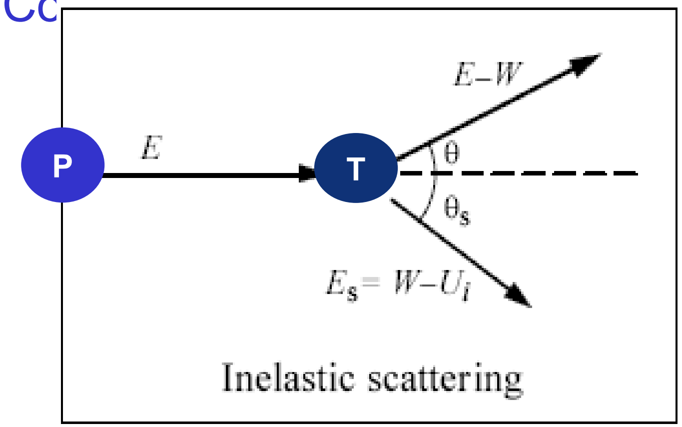
Range & Stopping Power in Nucleonica

Stopping Power; energy loss of energetic particles per unit length in matter.

The range; the mean path length of the particle in the target matter before coming t

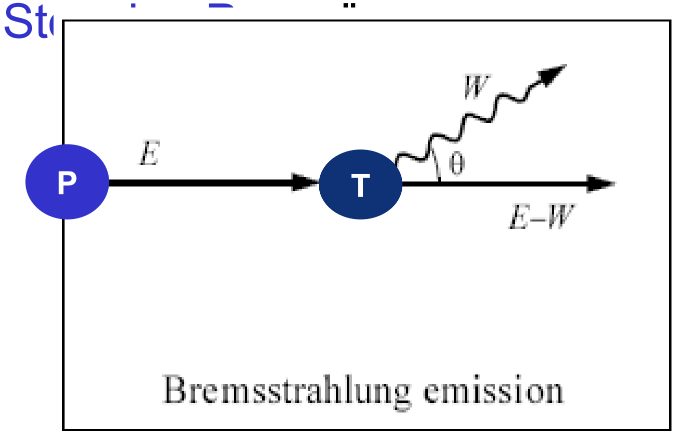
Types of Interactions

I. Inelastic scattering on atomic orbital electrons.
It leads to excitations and ionizations of atoms of the medium, and is called “Co



Inelastic scattering

II. Inelastic nuclear scattering.
This results in radiation which is known as “Bremsstrahlung”, so the stopping power is the “Radiative St



Bremsstrahlung emission

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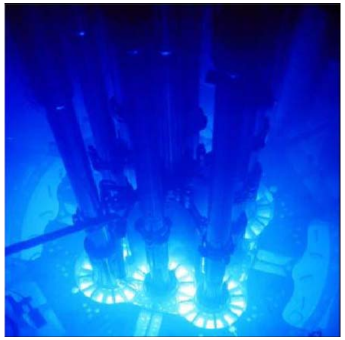
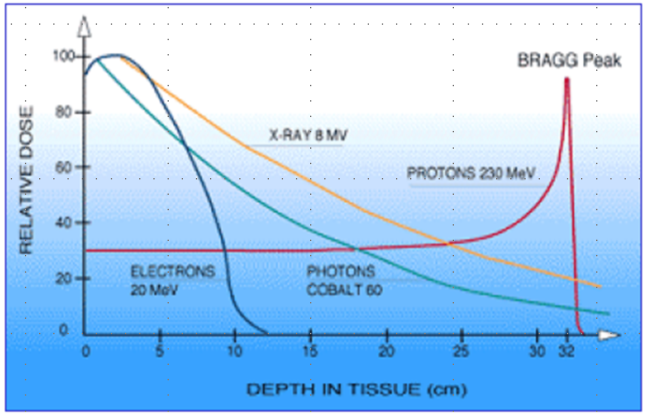
Aurora Borealis: interaction of electrons with oxygen and molecular nitrogen.



Čerenkov radiation: is radiation emitted when a charged particle) passes through matter at a speed greater than the speed of light in that medium. The characteristic "blue glow" of nuclear reactors is due to Čerenkov radiation**.**

Proton therapy: (used in treatment of tumours): 230 MeV p can penetrate in 32 cm tissue



wide application area: ion implantation, fundamental particle physics, nuclear physics, radiation damage, radiology, Rutherford backscattering spectroscopy, and plasma-first wall interaction in a nuclear-fusion reactor

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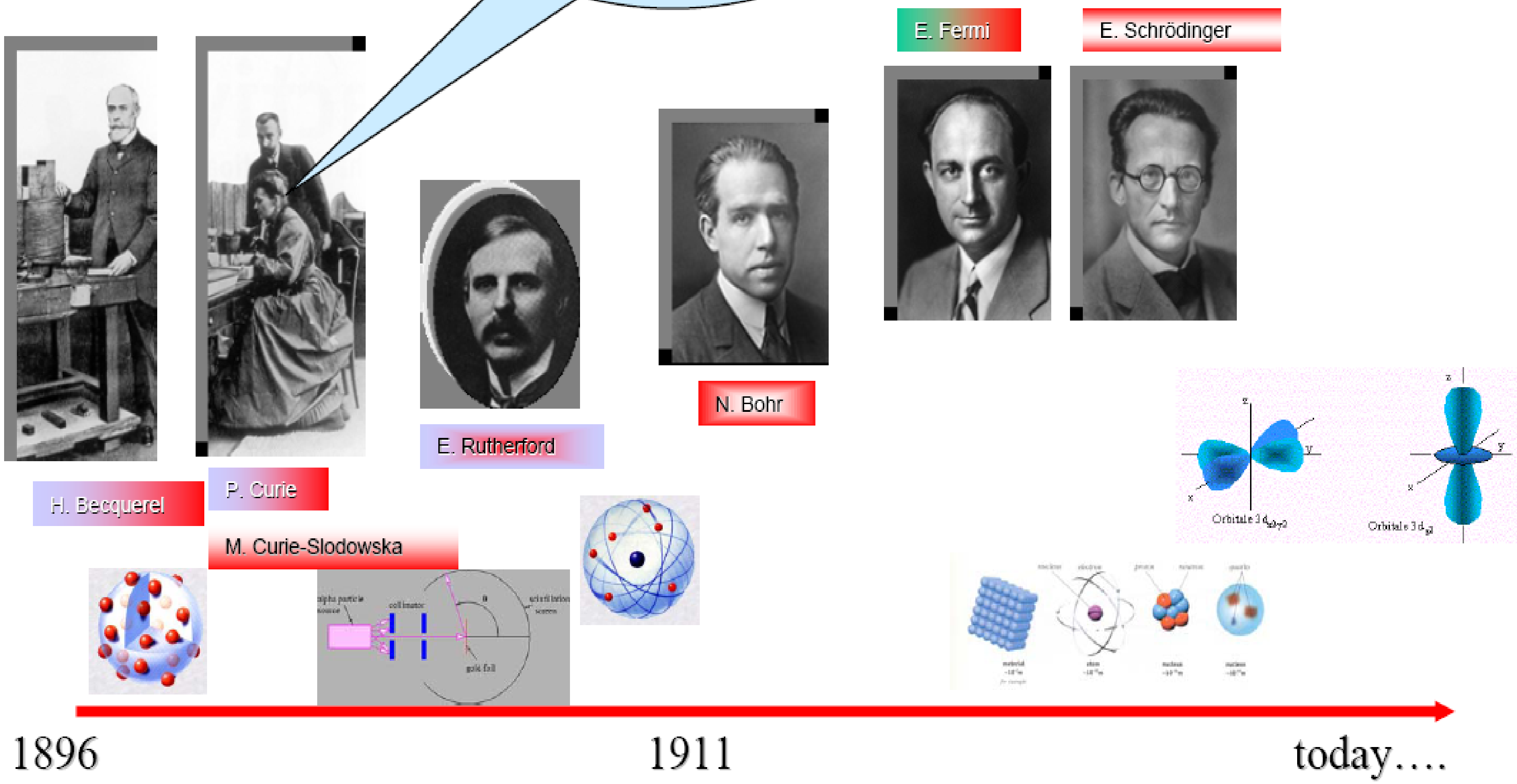
Some Pioneers:

"Les rayons alpha sont des projectiles matériels susceptibles de perdre de leur vitesse en traversant la matière" (1900)



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SHORT HISTORY

- The first study for scattering for two point charge was made by J.J. Thomson.

- In 1909, Geiger and Marsden experimented that scattering of alpha particles from gold foil and they observed that 0.1% of alpha particles backscattered from the target.

- Two years later from this experiment, E. Rutherford theoretically showed why this back scattering occurred, so nucleus was been found.

- After these improvements, in 1913 the energy loss of traversing particles per unit path (stopping power) was calculated theoretically by N. Bohr.

The first quantum mechanical treatment was done by Bethe in 1930

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Stopping power was studied

- for understanding atomic structure at the begining of 20. century.
- in 1920's for developing quantum mechanical scattering theory.
- for nuclear fission in 1930's and 1940's, in 1950's for nuclear physics.
- in 1960's for technological applications of ion implantation.
- in 1970's for material analyzing and radiation oncology.

Physics Behind the RANGE Module

- The RANGE module uses the SRIM "engine" for heavy ions, alphas and protons.

- Own codes for the calculations for electron, positron and muon projectiles.

- The interaction of incident electrons with target electrons can be calculated from Bethe’s theory.

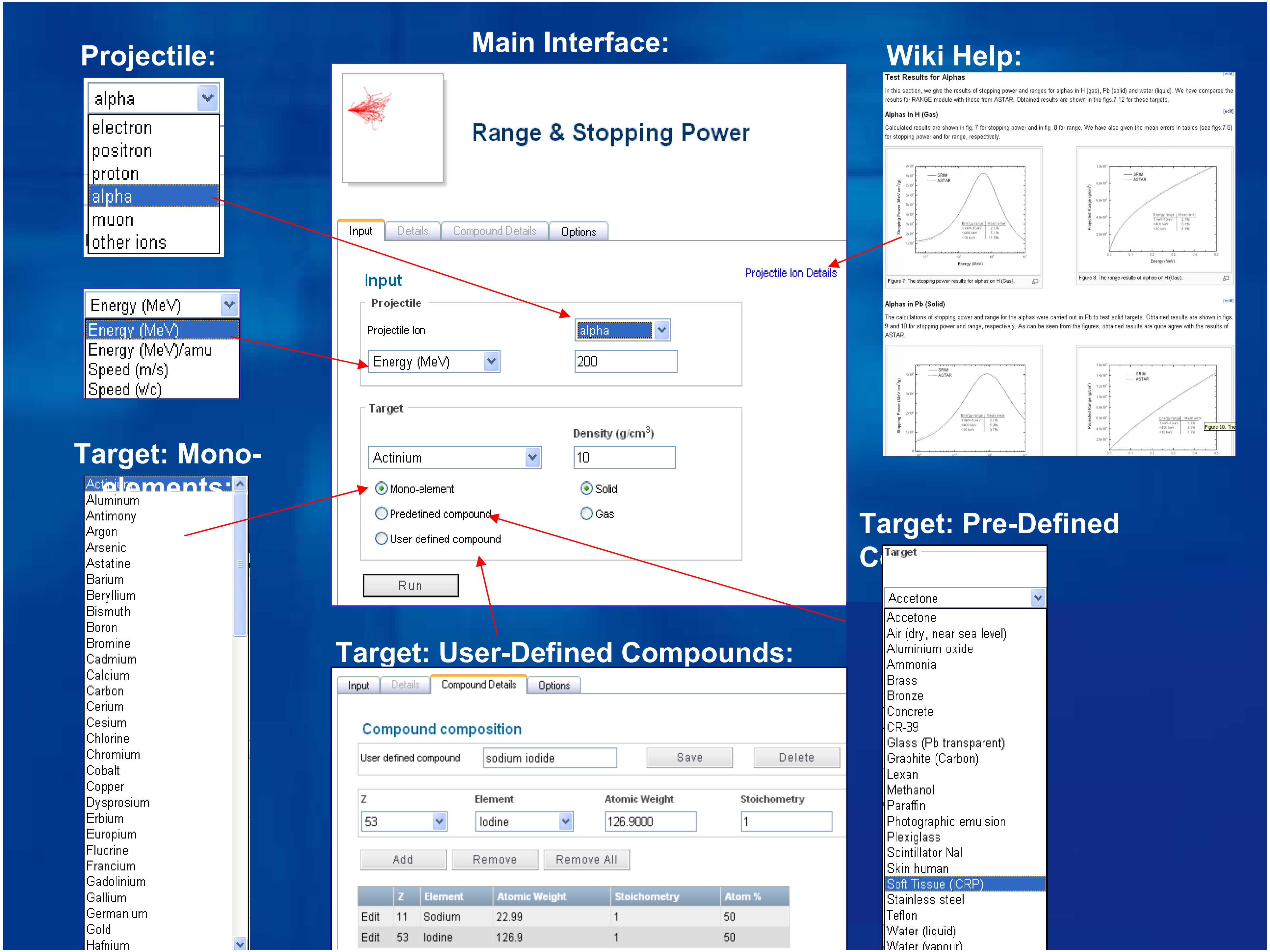
- The collisional stopping power of matter is calculated by considering the effective charge approximation.

- For Radiative Stopping Power, RANGE module uses simple ratio:

$$S_{rad}/S_{coll} = ZE/800$$

- Range of the electrons, positrons and muons in matter is calculated by using Continuous Slowing Down Approximation (CSDA):

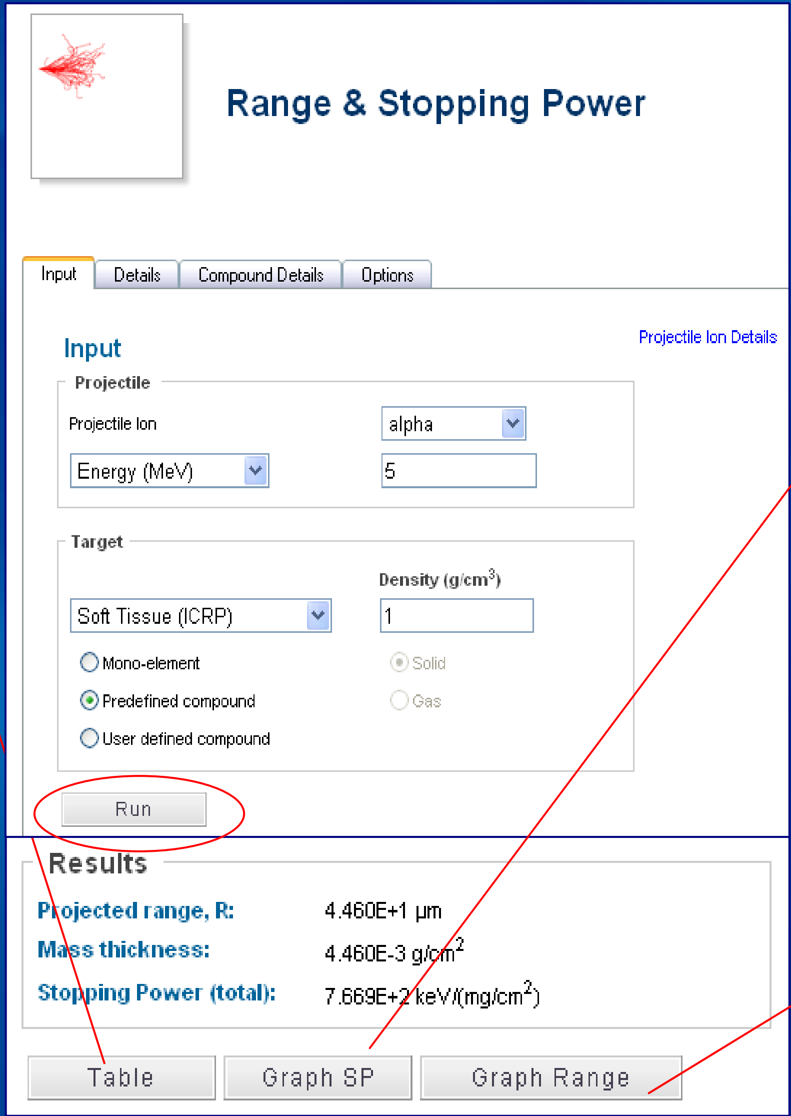
$$R(E) = \int_{E_{abs}}^{E} \frac{dE'}{S(E')}$$

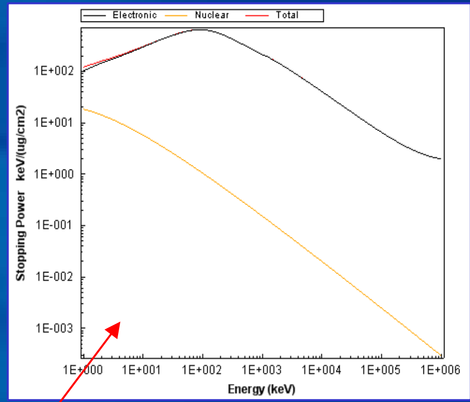

Projectile:
alpha
electron
positron
proton
alpha
muon
other ions
Energy (MeV)
Energy (MeV)
Energy (MeV)/amu
Speed (m/s)
Speed (v/c)
Main Interface:
Range & Stopping Power
Input
Details
Compound Details
Options
Input
Projectile Ion Details
Projectile
Projectile Ion
alpha
Energy (MeV)
200
Target
Density (g/cm3)
Actinium
10
Mono-element
Solid
Predefined compound
Gas
User defined compound
Run
Wiki Help:
Test Results for Alphas
In this section, we give the results of stopping power and ranges for alphas in H (gas), Pb (solid) and water (liquid). We have compared the results for RANGE module with those from ASTAR. Obtained results are shown in the figs.7-12 for these targets.
Alphas in H (Gas)
Calculated results are shown in fig. 7 for stopping power and in fig .8 for range. We have also given the mean errors in tables (see figs.7-8) for stopping power and for range, respectively.
Figure 7. The stopping power results for alphas on H (Gas).
Figure 8. The range results of alphas on H (Gas).
Alphas in Pb (Solid)
The calculations of stopping power and range for the alphas were carried out in Pb to test solid targets. Obtained results are shown in figs. 9 and 10 for stopping power and range, respectively. As can be seen from the figures, obtained results are quite agree with the results of ASTAR.
Target: Mono-elements:
Actinium
Aluminum
Antimony
Argon
Arsenic
Astatine
Barium
Beryllium
Bismuth
Boron
Bromine
Cadmium
Calcium
Carbon
Cerium
Cesium
Chlorine
Chromium
Cobalt
Copper
Dysprosium
Erbium
Europium
Fluorine
Francium
Gadolinium
Gallium
Germanium
Gold
Hafnium
Target: User-Defined Compounds:
Input
Details
Compound Details
Options
Compound composition
User defined compound
sodium iodide
Save
Delete
Z
Element
Atomic Weight
Stoichometry
53
Iodine
126.9000
1
Add
Remove
Remove All
Z | Element | Atomic Weight | Stoichometry | Atom %
Edit 11 Sodium 22.99 1 50
Edit 53 Iodine 126.9 1 50
Target: Pre-Defined Compounds:
Target
Accetone
Accetone
Air (dry, near sea level)
Aluminium oxide
Ammonia
Brass
Bronze
Concrete
CR-39
Glass (Pb transparent)
Graphite (Carbon)
Lexan
Methanol
Paraffin
Photographic emulsion
Plexiglass
Scintillator NaI
Skin human
Soft Tissue (ICRP)
Stainless steel
Teflon
Water (liquid)
Water (vapour)

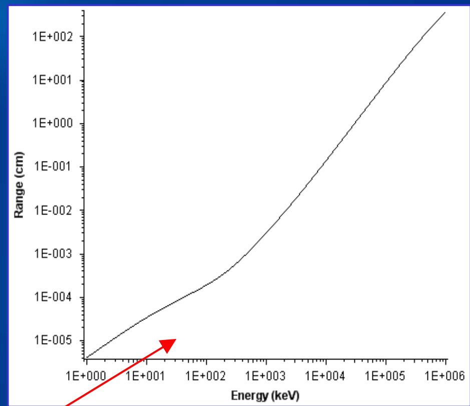
Results:

```
==================================================================
              Calculation using SRIM-2006
              SRIM version --->
              Calc. date    ---> April 07, 2008
==================================================================

Disk File Name = range_out2.txt

Ion = Helium       [2] , Mass = 4.002603 amu

Density =  1.0000E+00 g/cm3 = 4.4282E+22 atoms/cm3
======= Target  Composition =======
   Atom   Atom   Atomic    Mass
   Name   Numb   Percent   Percent
   ----   ----   -------   -------
     H      1    010.45    000.77
     C      6    023.22    020.51
     N      7    002.49    002.56
     O      8    063.02    074.15
    Na     11    000.11    000.19
    Mg     12    000.01    000.02
     P     15    000.13    000.30
     S     16    000.20    000.47
    Cl     17    000.13    000.35
     K     19    000.20    000.57
    Ca     20    000.02    000.07
    Fe     26    000.01    000.02
    Zn     30    000.00    000.01
====================================
Bragg Correction = 0.00%
Stopping Units =  keV/(mg/cm2)
See bottom of Table for other Stopping units

Ion = Helium       [2] , Mass = 4.002603 amu
```

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range
999.999 eV	9.609E+01	1.382E+02	224 A
1.10 keV	1.008E+02	1.364E+02	246 A
1.20 keV	1.053E+02	1.346E+02	267 A
1.30 keV	1.096E+02	1.328E+02	288 A







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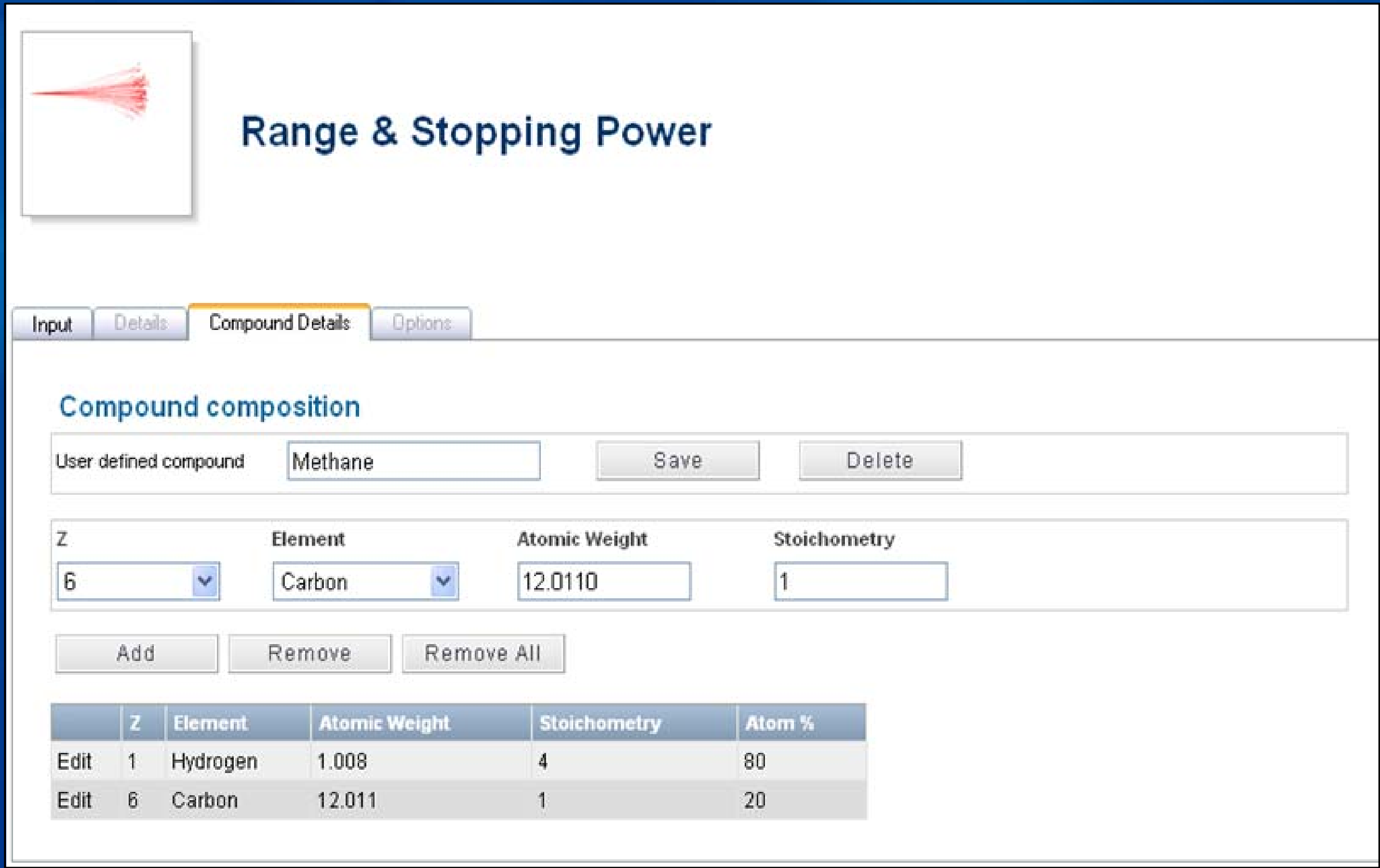
Target: User-defined compounds



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Range Calculations

[edit]

Most of the transport calculations and Monte Carlo simulations for the calculation of Range are based on the so-called Continuous Slowing Down Approximation (CSDA). In this approximation, it is assumed that the particle losses its energy in a continuous way and at a rate equal to the stopping power. Since the stopping power is the energy loss of projectile per unit path, CSDA range (or Bethe range) is calculated by

$$R(E) = \int_{E_{abs}}^{E} \frac{dE'}{S(E')}$$

where E_{abs} is the energy where particle is effectively absorbed. CSDA range is the path length traveled by the particle and since energy-loss fluctuations are not considered, CSDA range is always higher than projected range (R_p) which is the distance between the point where particle enters the stopping medium and the point where particle is absorbed (or come to rest). It becomes important when the projectile's energy is low enough.

SRIM uses PRAL (**P**rojected **R**ange **AL**gorithm) [6] equations for calculating projected range. To second order it involves iterating the difference equation

$$R_p(E_0 + \Delta E_0) = R_p(E_0) + \left[\frac{4E^2 - (2E\mu S_n + \mu Q_n)R_p(E_0)}{4ES_t - 2\mu Q_n}\right]\frac{\Delta E_0}{E}$$

Test Results for Protons

[edit]

We calculated the stopping powers and ranges of H (Gas), Pb (solid) and water (Liquid) for protons and compared the results with PSTAR.

Protons on H (Gas)

[edit]

As can be seen in fig.1, overall agreement with PSTAR is quite good. Comparing the RANGE module's results with PSTAR, the overall mean error in energy range from 1 keV to 1 GeV is 0.8 %, mean error is 1.8 % in energies below 400 keV and mean error in energies below 10 keV is 2.5 %.

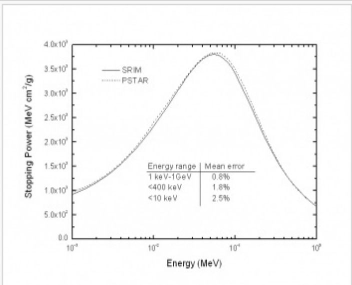

Figure 1. The stopping power results for protons in H (Gas).

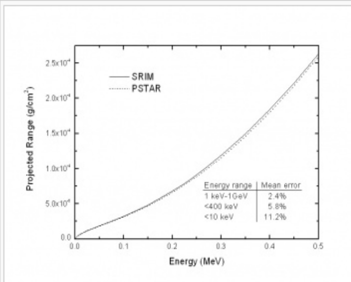

Figure 2. The range results of protons in H (Gas).

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Range and Stopping power

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Range Calculations with Nucleonica Scripting

Scripting language:

Classes	Main Methods
range	*CalculateMono()*
	CalculateCompound()
	CalculatePredefinedCompound()
	AddCompound()
	OriginConfigureSP()
	OriginGraphSP()
	OriginConfigureRange()
	OriginGraphRange()
rangeResult	*ProjRange(); massthickness();*
	StragLong(); StragLat(); etc.

CONCLUSIONS

The RANGE module:

- provides a user-friendly interface for quick and accurate calculations on the range and stopping powers of charged particles.
- can calculate SP and Range for electrons, positrons, protons, alphas, muons and heavy ions in a variety of different natural elements, pre-defined and user-defined compounds.
- Test results show agreements of less than 5% for protons and alphas, less than 10% for electrons and positrons, and less than 7% for muons for the total stopping powers and the CSDA Ranges. The Range module uses SRIM for heavy particles with a known accuracy of less than 5%.
- give freedom to the user for selecting the energy and stopping power units.
- provides high quality graphs for SP and Range.
- can be used in the Nucleonica scripting language.

Thanks!